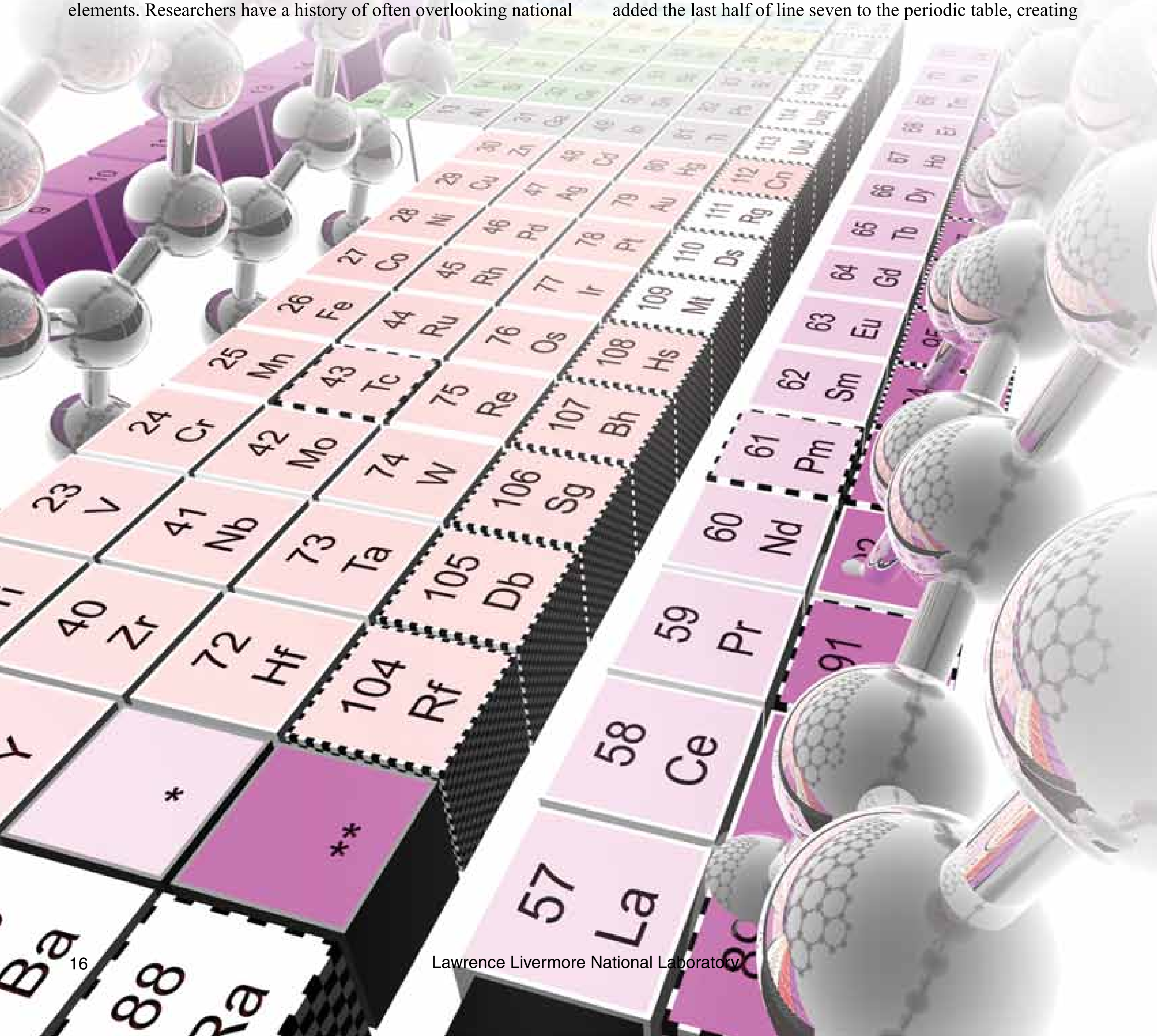
Collaboration Expands the Periodic Table, One Element at a Time

THE Laboratory's collaboration with the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, began in 1989 when Livermore's Ken Hulet and Professor Georgy Flerov of JINR met at a conference and agreed to work together to create superheavy elements. Researchers have a history of often overlooking national boundaries and internecine squabbles in the interest of advancing science. But this partnership was particularly remarkable because, says Livermore's Ken Moody, "the superheavy element community then was incredibly competitive." Together, this partnership has added the last half of line seven to the periodic table, creating



elements 113 to 118. The latest element, 117, was added in early 2010. Much of this research has been supported, in part, by Livermore's Laboratory Directed Research and Development Program, beginning with a project in 1995 to examine nuclear stability in heavy nuclei.

Nuclear chemists Ron Lougheed and Moody were the first Americans to perform experiments in Dubna, spending a month at JINR in 1990. It is easy today to forget how different times were in 1990. Both the U.S. and the Soviet Union were still testing nuclear weapons. The Berlin Wall had fallen, and although the Soviet Union was wobbling, it remained intact. Some Soviet states were beginning to flex their muscles, but they would not become independent until the next year.

"The Flerov Laboratory of Nuclear Reactions [at JINR], where we did our experiments, was founded by one of the giants of Russian nuclear physics," says Moody, who is still involved in the collaboration. As it happened, Flerov died shortly after the Livermore team arrived in 1990, and he was buried with honors in the same cemetery as the Russian playwright Anton Chekhov.

Although Flerov's death put a damper on work at the institute for the duration of the Laboratory scientists' visit, Lougheed and Moody would improve an energy- and position-sensitive technology that is still being used at JINR. Development of a gas-filled mass separator to remove unwanted nuclei from desired nuclei took many years. Finally, in 1999, the creation of the heaviest known elements began in earnest.

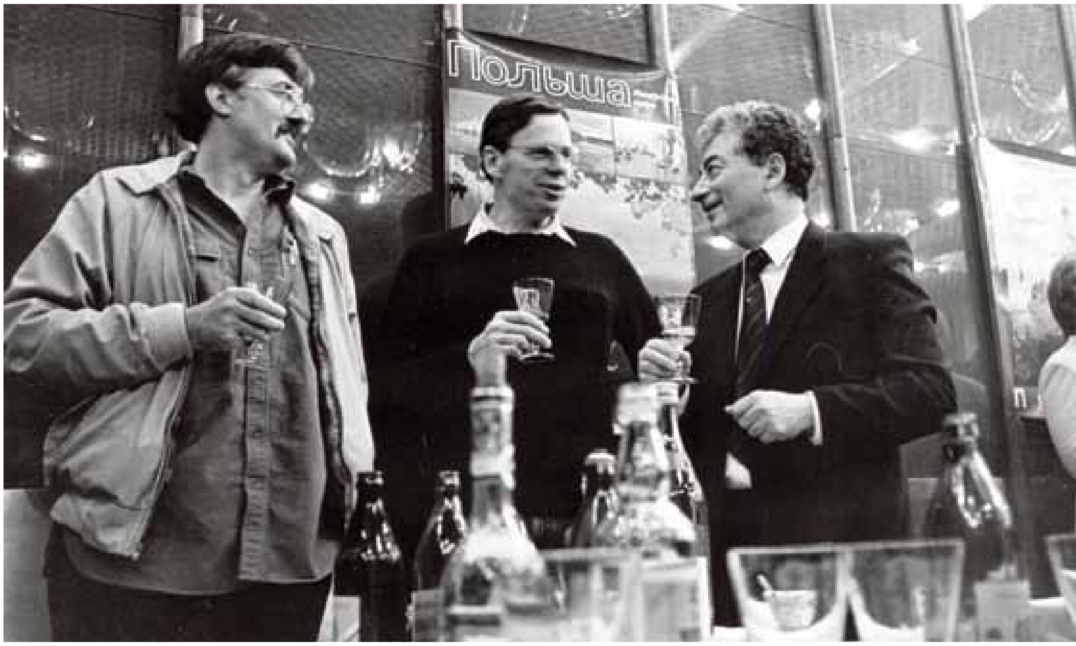
JINR, devoted solely to nuclear research of all types, is now almost as large as Lawrence Livermore with 5,500 staff members from all over the world. It houses accelerators and cyclotrons of varying energies for an array of experiments and commercial applications.

Creating New Elements

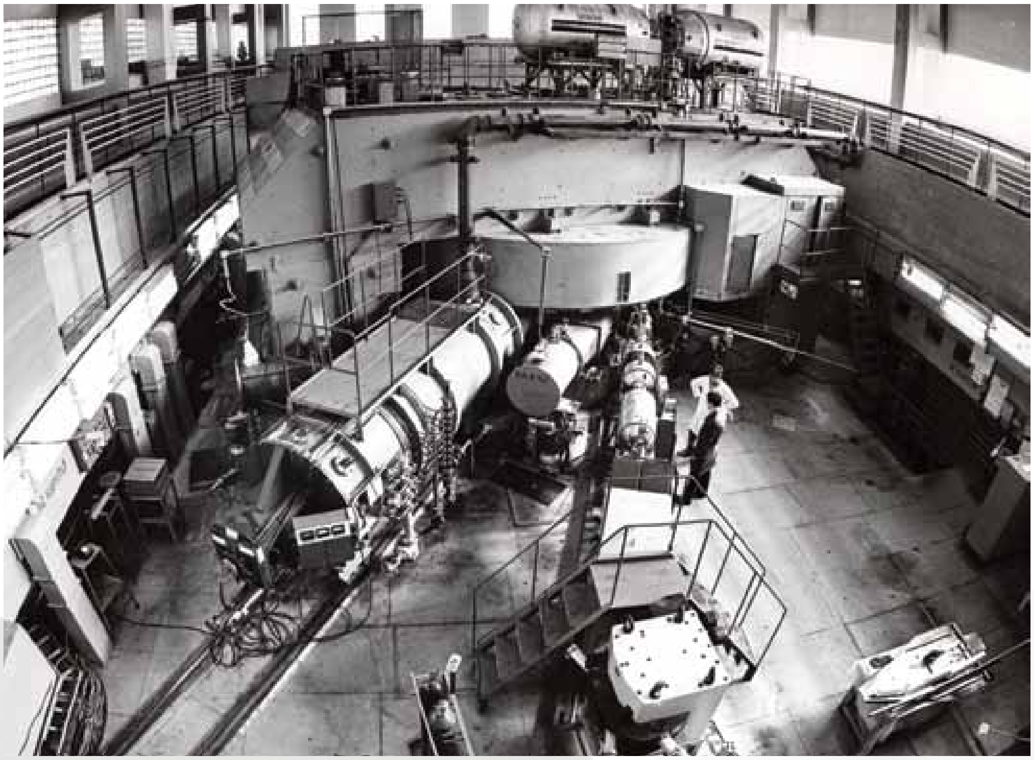
The number of an element in the periodic table—its atomic number—is defined by the quantity of protons in its nucleus. Most elements in the lower reaches of the periodic table—the gases and stable elements such as iron, copper, and calcium—have been known for hundreds of years. More unusual are elements 43 (technetium) and 61 (promethium), which were isolated and identified only with great difficulty after many years of research. Element 43, which was created in an Italian laboratory in 1937, is the lowest atomic-number element without any stable isotopes.

The highest atomic-number elements, beginning with neptunium and plutonium (elements 93 and 94), have all been created in the laboratory. Since the discovery of plutonium, scientists have fabricated 24 more elements, each one highly radioactive as well as heavier and, for the most part, with a shorter half-life than the one before it. Atoms can have multiple isotopes, depending on the number of neutrons in the atom. Element 114, for example, has an isotope called 114-289, which contains 289 nucleons in the nucleus (114 protons and 175 neutrons). Superheavy elements are those with a very high number of protons, beginning with element 104 (rutherfordium). Moody did his graduate work on superheavy elements at the University of California at Berkeley under Professor Glenn T. Seaborg (1912–1999), one of the great discoverers of heavy elements. Element 106, seaborgium, is named for him.

In the 1960s, a few physicists predicted that some superheavy elements would survive longer than any of their synthesized predecessors—a so-called "island of stability" in a sea of exceedingly short-lived elements. The very earliest estimates for the half-lives of these more stable elements were as high as billions of years. Later, computer modeling hugely reduced the



In 1990, Livermore's Ken Moody (left) and Ron Lougheed (center) joined Academician Yuri Oganessian (right), head of the Flerov Laboratory of Nuclear Reactions in Dubna, Russia, to toast the beginning of what became a 21-year collaboration to create superheavy elements.



New elements come to life, one atom at a time, in the U400 cyclotron at Flerov Laboratory of Nuclear Reactions.

anticipated half-lives to seconds or minutes before the element began to decay. Half-lives of seconds or minutes may seem brief, but some atoms have extremely short half-lives. For example, element 110 has isotopes with half-lives ranging from 100 microseconds to 1.1 milliseconds.

In vivid contrast, an atom of element 114, created by Livermore and JINR scientists in 1999, survived for 30 seconds before it began to decay—a spontaneous process that leads to the creation of another element with a lower number on the periodic table. A total of 34 minutes elapsed before the final decay product fissioned, splitting in two the surviving nucleus. These lifetimes are millions of times longer than those of previously synthesized heavy elements. The island of stability seemed tantalizingly close.

In 2000 and 2001, the collaboration used JINR's U400 cyclotron, one of the world's most powerful heavy-ion accelerators, to create element 116 in the hope of producing decay isotopes of element 114. Although the team did create several other isotopes repeatedly, some of which have since been duplicated, the long lifetime of the first atom of element 114 with 175 neutrons (114-289) has not been replicated. Similarly, element 118, created in 2006, lasted less than a millisecond before decaying.

The Challenges of Element 117

In bombarding one element with another, the number of protons in the two elements adds up to the protons in the desired new element. In element 118 experiments, californium, which has 98 protons, is fused with calcium, which has 20. The beam of calcium ions has to bombard the spinning californium target with enough force to fuse with the californium but not transfer enough energy to break apart the nucleus, or fission.

Researchers had initially skipped over element 117 because of difficulty obtaining the necessary target material, berkelium (element 97). Eventually, a two-year experimental campaign was begun at the High Flux Isotope Reactor at Oak Ridge National Laboratory with the goal of producing 22 milligrams of berkelium to discover element 117. A 250-day irradiation period was followed by 90 days of processing at Oak Ridge to separate and purify the berkelium target material. Collaborators at the Research Institute for Advanced Reactors in Dimitrovgrad, Russia, then prepared the targets. Over the next 150 days, the radioactive berkelium targets were bombarded with calcium ions in the U400 cyclotron at JINR. Finally, both Livermore and JINR analyzed the data. The entire process was driven by the 320-day half-life of the berkelium target material.

Livermore researchers (from left) John Wild (now retired), Dawn Shaughnessy, and Mark Stoyer flank a statue of Georgy Flerov, the nuclear physicist for whom the Flerov Laboratory of Nuclear Reactions is named.

The experimental campaign produced six atoms of element 117, each of which decayed to element 115, 113, and so on until fissioning. The observed decay patterns in the new isotopes continue the general trend of increasing stability for superheavy elements with increasing numbers of neutrons in the nucleus. As Lawrence Livermore Director George Miller has noted, "The discovery provides new insight into the makeup of the universe and is a testimony to the strength of science and technology at the partner institutions." However, true stability has not been found. The island of stability is near and yet still far.

Commonalities That Matter

Moody has visited Russia seven times, taking new members of the Livermore team each trip. He notes, "The country has become more westernized with every visit." By his fourth trip, Dubna had a Western-style supermarket, which was beginning to replace the individual meat, bread, and vegetable stalls. Chemist Dawn Shaughnessy, who has made four visits to JINR, noticed Coca-Cola® in an even larger supermarket during her most recent visit in September 2009. A postdoctoral fellow from Dubna, the first to come to the Laboratory, arrived this fall. According to Shaughnessy, he knows a freedom to travel and an availability of goods that surpass those experienced by his predecessors in the collaboration.

The U.S.–Russian team shares yet another commonality: the desire to continue the search for elements with properties unlike any others. Says Shaughnessy, "Each new element we discover provides more knowledge about the forces that bind nuclei and what causes them to split apart. This knowledge, in turn, helps us better understand the limits of nuclear stability and the fission process."

And what of the next elements on the periodic table? "Dubna is planning to upgrade the accelerator we use, increasing the intensity of the ion beams it produces," says Shaughnessy. "Another expected change is that the accelerator will be capable of producing beams of elements other than calcium." Fusing iron and plutonium to create element 120 will require crushing energies and a whole new ion elemental beam.

—Katie Walter

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